

## PATENT ABSTRACTS OF JAPAN

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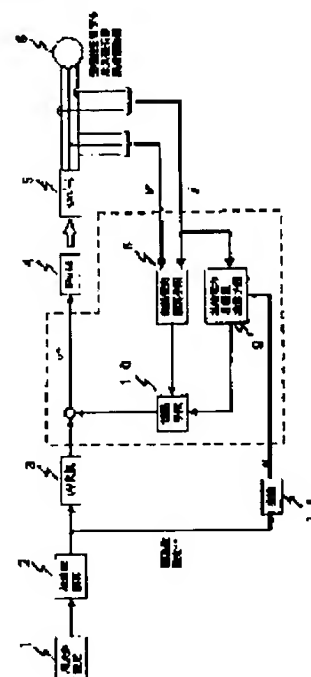
ITOIGAWA NOBUO

## (54) CONTROLLER FOR PERMANENT MAGNET-TYPE SYNCHRONOUS MOTOR

## (57)Abstract:

**PROBLEM TO BE SOLVED:** To attain simple control in a V/f control for a permanent magnet-type synchronous motor having saliency for highly efficient operation, by computing the actual value of reactive power and a target value thereof, and regulating voltage applied to the winding of the motor so that the actual value and the target value of the reactive power may be equal to each other.

**SOLUTION:** The detected values of voltage (v) and current (i) of a permanent magnet-type synchronous motor 6 having saliency are introduced into a reactive power computing means 8 for computing the actual value of the reactive power inputted into the motor 6. A target value computing means 9 computes the target value of the reactive power which should be inputted into the motor 6 using the conditional expression of a high efficient operation. A converting means 11 for converting a frequency setting value (f) to angular frequency ( $\omega$ ) for computing the reactive power target value is mounted. A regulating means 10 feeds back the value which acts on so that the reactive power inputted into the motor 6 may become equal to the target value to a voltage command (v) outputted by a f/V means 3. It is thus possible to attain maximum torque control in the V/f control, thereby attaining high efficiency.



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## DETAILED DESCRIPTION

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### [Detailed Description of the Invention]

[0001]

[The technical field to which invention belongs] this invention relates to the control unit for it being efficient and operating the permanent magnet form synchronous motor which has a saliency like embedded magnet structure using semiconductor power converters, such as an inverter.

[0002]

[Description of the Prior Art] The position detection value which generally detects the position of a rotator is required, and the phase of current is controlled by control of synchronous motors, such as a permanent magnet form synchronous motor and a reluctance motor, synchronizing with the position of the detected rotator. The hall device, the encoder, the resolver, etc. are used as a detector. Or the so-called position-sensor less control which calculates the position of a rotator electrically is also known from the voltage of a motor, or the information on current.

[0003] Efficient operation in the case of detecting or asking for the position of a rotator according to an operation can be realized comparatively easily. Generally the  $I_d=0$  control which makes it zero, the current, i.e., d shaft current, of the direction of magnetic flux from which a permanent magnet makes a permanent magnet in the permanent magnet form synchronous motor (it is hereafter called an SPM motor.) of surface magnet structure attached in the rotator front face, is adopted. In the case of an SPM motor, d shaft current is because copper loss can be stopped by  $I_d=0$  control to the minimum in order not to contribute to torque.

[0004] Moreover, in the permanent magnet form synchronous motor (it is hereafter called an IPM motor.) of the embedded magnet structure which embedded the permanent magnet to the interior of a rotator, a magnetic circuit becomes unsymmetrical, a saliency arises and the maximum torque control using the reluctance torque by this saliency is adopted. Torque/current maximizes in this maximum torque control. That is, since current always minimizes to desired torque, copper loss can be stopped to the minimum.

[0005] The V/f control which the applied voltage and frequency of a synchronous motor other than a method which detect or calculate the position of a rotator as mentioned above on the other hand are made to be only proportional, and controls them is also known. The control-block view of V/f control is shown in drawing 8. The frequency of the motor for which it asks by the frequency setting means 1 is set up, and frequency is changed in the shape of a lamp function by the acceleration-and-deceleration operation means 2. With the f/V conversion means 3, the voltage mostly proportional to frequency is called for by storage or calculation, and voltage instruction  $v^*$  is outputted according to frequency instruction  $f^*$ .

[0006] The addition means 7 integrates with frequency instruction  $f1^*$  which it is as a result of [ of frequency instruction  $f^*$  and frequency amendment component  $\Delta f^*$  from the stabilization control means 30 mentioned later ] addition, and calculates the phase theta of the voltage impressed to the coil of a motor 6. The PWM means 4 inputs the size and phase theta of voltage instruction  $v^*$ , performs PDM, and controls the switching element which constitutes an inverter 5. From an inverter 5, the alternating voltage by which pulse width control was carried out is outputted, and it is impressed by the coil of the permanent magnet form synchronous motor 6.

[0007] V/f control has a problem in stability, such as torque vibrating regularly, or carrying out step-out and becoming operation impotentia, when a load changes suddenly. Then, it asked for the current component  $i_Q$  and the parallel current component  $i_P$  which intersect perpendicularly with the voltage vector  $v$  through the three phase circuit / 2 phase conversion means 31, and the coordinate transformation means 32 from the primary current of a motor 6 by the stabilization control means 30 shown in the dashed line of drawing 8, and amendment component  $\Delta f^*$  was computed by having subtracted and added through high-pass filters 33 and 34 and linear amplifiers 35 and 36, this was returned to frequency instruction  $f^*$  of voltage, and stability is improved.

[0008]

[Problem(s) to be Solved by the Invention] While performing maximum torque control by  $I_d=0$  control and the IPM motor, and operating efficient by the SPM motor can be realized easily, the miniaturization of equipment is difficult for the control unit with a position transducer. Moreover, since the wiring of two or more and the receiving circuit which tell the signal of a detector are required, reliability, workability, and the price also have the problem. Furthermore, in position-sensor less control, while a position sensor is unnecessary, in order to ask for a rotor position, a high-speed and highly efficient operation is required, and an expensive control unit becomes indispensable.

[0009] It was difficult to perform maximum torque control etc. in  $I_d=0$  control and an IPM motor in an SPM motor, and to operate efficient on the other hand, since the position of a rotator is unknown, although the conventional V/f control has an unnecessary position transducer and control can moreover make an easy hatchet control unit cheap. For example, since the voltage beforehand decided to the output frequency was impressed to the motor regardless of the state of a load, when the value to which the voltage decided beforehand becomes suitable in the state of a rated load, then a load become light, excessive voltage will be supplied, consequently unnecessary current flows, loss increases, and V/f control poses a problem from a viewpoint of energy saving.

[0010] About this point, these people proposed the control unit which realizes  $i_d=0$  control in equivalent by V/f control as Japanese Patent Application No. 11-33025 about the SPM motor, and have solved the above-mentioned problem. Then, this invention tends to solve the above-mentioned problem in the permanent magnet form synchronous motor which has a saliency like an IPM motor, and tends to offer the control unit of the synchronous motor which can be operated efficient with easy and cheap composition.

[0011]

[Means for Solving the Problem] A means for this invention to make the voltage fundamentally impressed to the coil of the permanent magnet form motor which has saliencies, such as embedded magnet structure, be proportional to its frequency mostly, and to control in order to solve the above-mentioned technical problem, It has an adjustment means to adjust the voltage impressed to the aforementioned coil so that a means to calculate the actual value of the reactive power inputted into the motor, a means to calculate the desired value of the reactive power which should be inputted into the aforementioned motor, and the actual value and desired value of the aforementioned reactive power may become equal.

[0012] Hereafter, the principle of this invention is explained. The reactive power inputted into the motor can calculate voltage and current by regarding as a vector. Although various axes of coordinates can take as an axis of coordinates of a vector, the method of a claim 2 is explained here, referring to drawing 5 and drawing 6.

[0013] As shown in drawing 5, the P-Q rectangular coordinates which took the direction of the voltage vector  $v$  impressed to the coil of a motor on P shaft are considered. A P-Q axis of coordinates presupposes that the d-q rectangular coordinates and the crossing angle which took the direction of magnetic flux which a permanent magnet makes on d shaft are  $\delta$ . In addition, this crossing angle is mostly equivalent to the angle called the load angle or internal phase angle of a synchronous motor. If a current phasor is set to  $i$ , this vector  $i$  can be decomposed into the P shaft current  $i_P$  observed on the P-Q shaft, the Q shaft current  $i_Q$ , or the d shaft current  $i_d$  and the q shaft current  $i_q$  observed on the d-q shaft. Here, since the voltage vector  $v$  and the Q shaft current  $i_Q$  lie at right angles, they can ask for the reactive power  $Q_i$  inputted into the motor from both product, and can express it with a formula 1 using voltage magnitude-of-a-vector  $V$ .

[0014]

[Equation 1]  $Q_i = V i_Q$  [0015] On the other hand, reactive power can also be calculated using the equivalent circuit constant of a motor etc., and this is explained, referring to drawing 6. A size is expressed with  $\omega \psi_{sim}$  and the induced voltage generated because flux-linkage  $\psi_{sim}$  which a permanent magnet makes rotates with angular frequency  $\omega$  exists on q shaft. The size is expressed in drawing 6 as  $e_m$ . A product with the current  $i_d$  which intersects perpendicularly with this induced voltage, i.e.,  $\omega \psi_{sim} i_d$ , serves as reactive power. Moreover, the size of the reactance drop voltage by Current  $i_d$  serves as  $\omega L_d i_d$  using the inductance  $L_d$  of d shaft. The size is expressed in drawing 6 as  $e_{Ld}$ .

[0016] Since this reactance drop voltage  $e_{Ld}$  ( $=\omega L_d i_d$ ) and the d shaft current  $i_d$  are in orthogonality relation, reactive power is served as, both product 2, i.e.,  $\omega L_d i_d^2$ . Furthermore, the size of the reactance drop voltage by the q shaft current  $i_q$  serves as  $\omega L_q i_q$  using the inductance  $L_q$  of q shaft. The size is expressed in drawing 6 as  $e_{Lq}$ . Since this reactance drop voltage  $e_{Lq}$  ( $=\omega L_q i_q$ ) and the q shaft current  $i_q$  are in orthogonality relation, reactive power is served as, both product 2, i.e.,  $\omega L_q i_q^2$ . Therefore, a formula 2 can express the reactive power  $Q_m$  obtained from the above-mentioned consideration.

[0017]

[Equation 2]  $Q_m = \omega \psi_m i_d + \omega L_d i_d^2 + \omega L_q i_q^2$  [0018] Only by views differing, as for the reactive power which can be found with a formula 1 and a formula 2, since a value is equal, the relation shown with a formula 3 is materialized.

[0019]

[Equation 3]  $V_i Q = \omega \psi_m i_d + \omega L_d i_d^2 + \omega L_q i_q^2$  [0020] A formula 3 is a formula showing the relation of the reactive power in an IPM motor, and this invention is not directly related to the target efficient operation. Then, the conditional expression for carrying out efficient operation of the IPM motor is substituted for the right-hand side of a formula 3, and it considers as the desired value of the reactive power into which the value should be inputted by the motor, and the reactive power inputted into a motor is adjusted by controlling so that the actual value of the reactive power of a motor expressed with the left part of a formula 3 becomes equal to desired value, and it becomes possible to operate an IPM motor efficient.

[0021] Here, in order to carry out efficient operation of the IPM motor, it explains using the conditional expression of maximum torque control. The conditional expression of maximum torque control is shown below (Institute of Electrical Engineers of Japan study group data "many properties of ring magnet flush-type PM motor" RM-95 -15 reference).

[0022]

[Equation 4]

$\{\psi_m + (L_d - L_q) i_d\} i_d - (L_d - L_q) i_q^2 = 0$  [0023] If there is a position transducer which detects the position of a rotator, efficient operation according to maximum torque control by constituting a control system so that  $i_d$  and  $i_q$  may be easily found by coordinate transformation and a formula 4 may be filled is possible. However, when there is no position transducer, it is difficult to calculate  $i_d$  and  $i_q$ . Then, it considers realizing maximum torque control by the IPM motor using  $i_P$  and  $i_Q$  which are calculated comparatively easily, or  $i_P^2 + i_Q^2 = I^2 (= i_d^2 + i_q^2)$ . First, it will become a formula 5 if  $i_q^2 = I^2 - i_d^2$  which can be found from the above-mentioned  $I^2 = i_d^2 + i_q^2$  is substituted and arranged to a formula 4.

[0024]

[Equation 5]

$2(L_d - L_q) i_d^2 + \psi_m i_d - (L_d - L_q) I^2 = 0$  [0025] It will become a formula 6 if a formula 5 is solved about  $i_d$ .

[0026]

[Equation 6]

$$i_d = \frac{-\psi_m \pm \sqrt{\psi_m^2 + 8(L_d - L_q)^2 I^2}}{4(L_d - L_q)}$$

[0027] Since it is always necessary to control the d shaft current  $i_d$  to negative in order to use reluctance torque by the IPM motor, if  $L_d < L_q$  is taken into consideration, since  $i_d$  serves as negative when taking +, the decode of a formula 6 will serve as the following formulas 7.

[0028]

[Equation 7]

$$i_d = \frac{-\psi_m + \sqrt{\psi_m^2 + 8(L_d - L_q)^2 I^2}}{4(L_d - L_q)}$$

[0029] It will become the following formulas if  $i_q^2 = I^2 - i_d^2$  is substituted and arranged to the right-hand side of the formula 3 showing the relation of the reactive power in an IPM motor.

[0030]

[Formula 8]

$V_i Q = \omega (L_d - L_q) i_d^2 + \omega \psi_m i_d + \omega L_q I^2$  [0031] It will become a formula 9 if a formula 7 is substituted for a formula 8.

[0032]

[Equation 9]

$$V_{iQ} = \omega \left[ \frac{(L_d + L_q)}{2} I^2 - \frac{\psi_m}{8} \left( \frac{\psi_m}{L_d - L_q} + \sqrt{\left( \frac{\psi_m}{L_d - L_q} \right)^2 + 8I^2} \right) \right]$$

[0033] The above-mentioned formula 9 expresses the basic principle of this invention. That is, the left part of a formula 9 is the desired value of the reactive power to which the right-hand side of the actual value of reactive power and a formula 9 added the conditions of maximum torque control, and efficient control of the IPM motor can be carried out by controlling so that both sides become equal.

[0034] Next, the formula of maximum torque control of a formula 5 is expressed in approximation, and it considers simplifying control composition. If five is solved about a formula 12, it will become the following formulas 10.

[0035]

[Equation 10]  $I_2 = 2id_2 + \{\psi_m / (L_d - L_q)\} id$  [0036] Generally,  $\psi_m / (L_d - L_q)$  is fully large compared with d shaft current. In the case of such conditions, the following relational expression is realized.

[0037]

[Equation 11]  $2id(s)^2 \ll \{\psi_m / (L_d - L_q)\} id$  [0038] From the relation of this formula 11, a formula 10 is approximated as follows.

[0039]

[Equation 12]  $I_2 = k id$  [0040] The coefficient k in a formula 12 is rewritten and a formula 13 is obtained.

[0041]

[Equation 13]  $id = KI_2$  (it sets with  $1/k = K$ .)

[0042] It will become the following formulas if a formula 13 is substituted for a formula 8.

[0043]

[Equation 14]  $V_{iQ} = \omega I_2 \{ (L_d + L_q + \psi_m - K) / 2 \} = \omega I_2, KM$  ( $KM = (L_d + L_q + \psi_m - K) / 2$ )

[0044] Therefore, if approximated like the above-mentioned formula 12, approximation maximum torque control is realizable by easy circuitry with a formula 14. The operation is the same, even if it replaces with voltage magnitude-of-a-vector V of a formula 14 and uses instruction value  $V^*$  of V.

[0045]

[Embodiments of the Invention] Hereafter, the operation form of this invention is explained, referring to a drawing. Drawing 1 is the operation form of invention concerning a claim 1, and is the control-block view showing efficient operation of a permanent magnet form synchronous motor. The portion enclosed with the dashed line is the function added in this operation form. The stabilization control means shown in the conventional technology of drawing 8 omit illustration. Since dashed line outside is the conventional technology, below, it explains only the inside of a dashed line.

[0046] A claim 1 expresses the fundamental concept of this invention. In drawing 1, like an IPM motor, the voltage of the permanent magnet form synchronous motor 6 which has a saliency, and current are incorporated by the reactive power operation means 8, and the actual value of the reactive power inputted into the motor 6 by this operation means 8 calculates them with the above-mentioned formula 1. Moreover, the desired value of the reactive power which should be inputted into a motor 6 by the reactive power desired value operation means 9 using the conditional expression (right-hand side of the above-mentioned formula 14 or a formula 9) of efficient operation is calculated. In addition, 11 is a conversion means to change frequency setting value  $f^*$  into angular frequency  $\omega$  for the operation of reactive power desired value. And it returns to voltage instruction  $v^*$  whose value which acts so that the reactive power inputted into the motor may become equal to desired value by the regulation means 10 is the output of the  $f/V$  conversion means 3.

[0047] Thereby, in the IPM motor by which V/f control is carried out, maximum torque control can be enabled and efficient operation can be performed.

[0048] Drawing 2 is the control-block view showing the operation form of invention concerning a claim 2. In drawing 2, the current  $i_u$  and  $i_w$  of two detected phases is transformed into the current component  $i_Q$  which intersects perpendicularly with a voltage instruction vector by the coordinate transformation means 12, and the current component  $i_P$  parallel to a voltage instruction vector. With the reactive power operation means 8, the actual value of reactive power is calculated from a voltage instruction vector and a current component  $i_Q$ . Moreover, the reactive power desired value operation means 9 calculates the desired value of reactive power using current components  $i_Q$  and  $i_P$ , the equivalent circuit constants ( $L_d$ ,  $L_q$ ,  $\psi_m$ , etc.) 13 of a motor 6, and angular frequency  $\omega$ . The value

which acts so that the actual value of the reactive power inputted into the motor 6 may become equal to desired value by the regulation means 10 returns to voltage instruction  $v^*$ .

[0049] Drawing 3 is the control-block view showing the operation gestalt of invention concerning a claim 3. In drawing 3, I2 operation means 15 asks for the square of the size of current according to the operation expression of  $I2=iP2+iQ2$ , multiplies by  $**** KM = (Ld+Lq+\psi mK) / 2$  shown in the parenthesis of the aforementioned formula 14, carries out the multiplication of the angular frequency  $\omega$  with a multiplier 17 further, calculates  $\omega \{(Ld+Lq+\psi mK) / 2\} I2$ , and makes this the desired value of reactive power. On the other hand, the multiplication of voltage instruction  $v^*$  and the  $iQ$  is carried out by the reactive power operation means 8, and  $v^*iQ$  is calculated.

[0050] Such  $\omega \{(Ld+Lq+\psi mK) / 2\}$  The difference of I2 and  $v^*iQ$  is taken and the value is made into  $**$ .  $**$  is inputted into a controller 16 and generates amendment  $**v^*$  for voltage instruction  $v^*$ . It expresses that the reactive power actually inputted when  $**$  is + (plus) is larger than target reactive power, and the impressed voltage is excessive, and since too little [ the reactive power which is actually inputted in - (minus) is smaller than target reactive power, and / voltage ] is expressed, negative feedback of  $**v^*$  is carried out to voltage. In addition, in drawing 3, 14 is an addition means and 18 is a three phase circuit / 2 phase conversion means.

[0051] The concrete composition of the controller 16 in drawing 3 is explained referring to drawing 7. In drawing 7, when PI controller with which example  $**$  combined the proportional element and the integral element when example  $**$  gave a first order lag element is constituted and example  $**$  gives a proportional element, example  $**$  is the case where an integral element is given. At the point with the function to adjust voltage so that  $**$  of reactive power desired value and the input which is actually deflection with a value may be made into zero in any case, the purpose is common.

[0052] Moreover, drawing 4 is the control-block view showing the operation gestalt of invention concerning a claim 4, and the portion enclosed with the dashed line differs from the operation gestalt of drawing 3. Based on the following formula which transforms a formula 14 and can be found, the control circuit consists of this operation gestalt.

[0053]

[Equation 15]  $V_iQ/\omega = \{(Ld+Lq+\psi mK) / 2\} I2 = KM - I2$  [0054] In drawing 4, according to the operation expression of  $I2=iP2+iQ2$ , it asks for the square of the size of current by I2 operation means 15, and the multiplication of the  $**** KM = (Ld+Lq+\psi mK) / 2$  as drawing 3 is carried out, and  $\{(Ld+Lq+\psi mK) / 2\} I2$  are calculated.

[ same ] On the other hand, the product of voltage  $v^*$  and  $iQ$  is  $**$ (ed) with angular frequency  $\omega$  by the divider 19, and  $/(v^*iQ) \omega$  is calculated.  $(v^*iQ) / \omega$  The difference of  $/(v^*iQ) \omega$  and  $\{(Ld+Lq+\psi mK) / 2\} I2$  is taken, and the value is made into  $**$ .  $**$  is inputted into a controller 16 and generates amendment  $**v^*$  for voltage instruction  $v^*$ .

The composition of a controller 16 is the same as drawing 7.

[0055] Thus, efficient operation is possible if the same controller 16 as the operation gestalt of drawing 3 constitutes a control circuit using the value proportional to the actual value of the reactive power inputted into the motor 6, and the value proportional to the desired value of the reactive power of a motor 6. Moreover, even if it uses the value which adjusted the same value from the actual value of the reactive power inputted into the motor 6, and the desired value of reactive power, it is clear that the same effect is acquired.

[0056]

[Effect of the Invention] As mentioned above, according to this invention, it is the control unit of the permanent magnet form synchronous motor which has saliencies, such as embedded magnet structure, and easy control can realize efficient operation in the V/f control which the voltage impressed to a coil is made to be proportional to its frequency mostly, and drives it. That is, conventionally, realization of the maximum torque control carried out by the driving gear with a magnetic pole position transducer is enabled [ having no detector and ], the function to adjust voltage to the V/f control which supplies voltage to a target on the other hand according to a load effect is added, and there is an effect of demonstrating the energy-saving effect.

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DESCRIPTION OF DRAWINGS

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[Brief Description of the Drawings]

- [Drawing 1] It is the control-block view showing the operation gestalt of invention indicated to the claim 1.  
[Drawing 2] It is the control-block view showing the operation gestalt of invention indicated to the claim 2.  
[Drawing 3] It is the control-block view showing the operation gestalt of invention indicated to the claim 3.  
[Drawing 4] It is the control-block view showing the operation gestalt of invention indicated to the claim 4.  
[Drawing 5] It is drawing explaining the principle of this invention.  
[Drawing 6] It is drawing explaining the principle of this invention.  
[Drawing 7] It is the block diagram of the controller in drawing 3 and drawing 4 .  
[Drawing 8] It is the control-block view showing the conventional technology.

[Description of Notations]

- 1 Frequency Setting Means
- 2 Acceleration-and-Deceleration Operation Means
- 3 F/V Conversion Means
- 4 PWM Means
- 5 Inverter
- 6 Permanent Magnet Form Synchronous Motor
- 8 Reactive Power Operation Means
- 9 Reactive Power Desired Value Operation Means
- 10 Regulation Means
- 11 Conversion Means
- 12 Coordinate Transformation Means
- 13 Equivalent Circuit Constant of Motor
- 14 Addition Means
- 15 I2 Operation Means
- 16 Controller
- 17 Multiplication Means
- 18 Three Phase Circuit / 2 Phase Conversion Means
- 19 Division Means

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## DRAWINGS

例 16 制御系

Δ →  $\left[ \frac{K_p}{1+sT} \right] \rightarrow \Delta v$  例①

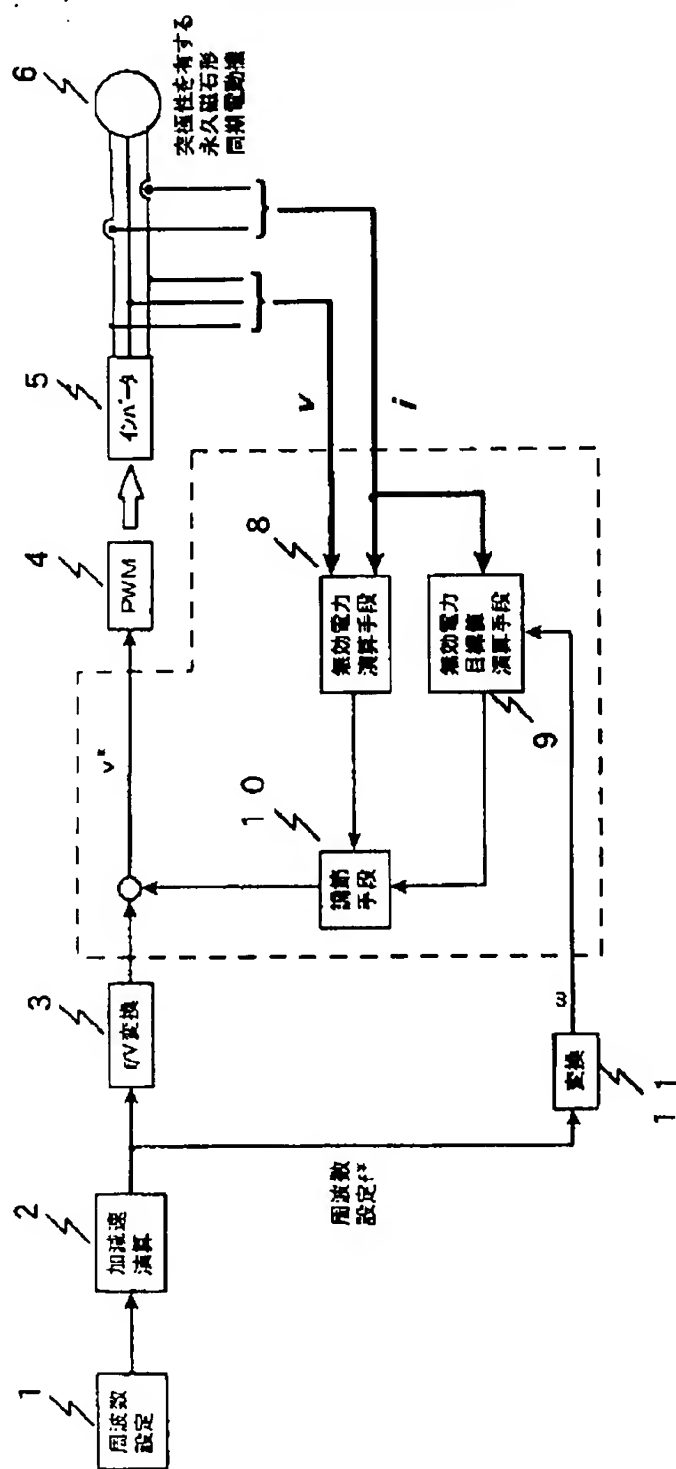
---  $\left[ K_p \left( 1 + \frac{1}{sT} \right) \right] \rightarrow$  例②

---  $\left[ K_p \right] \rightarrow$  例③

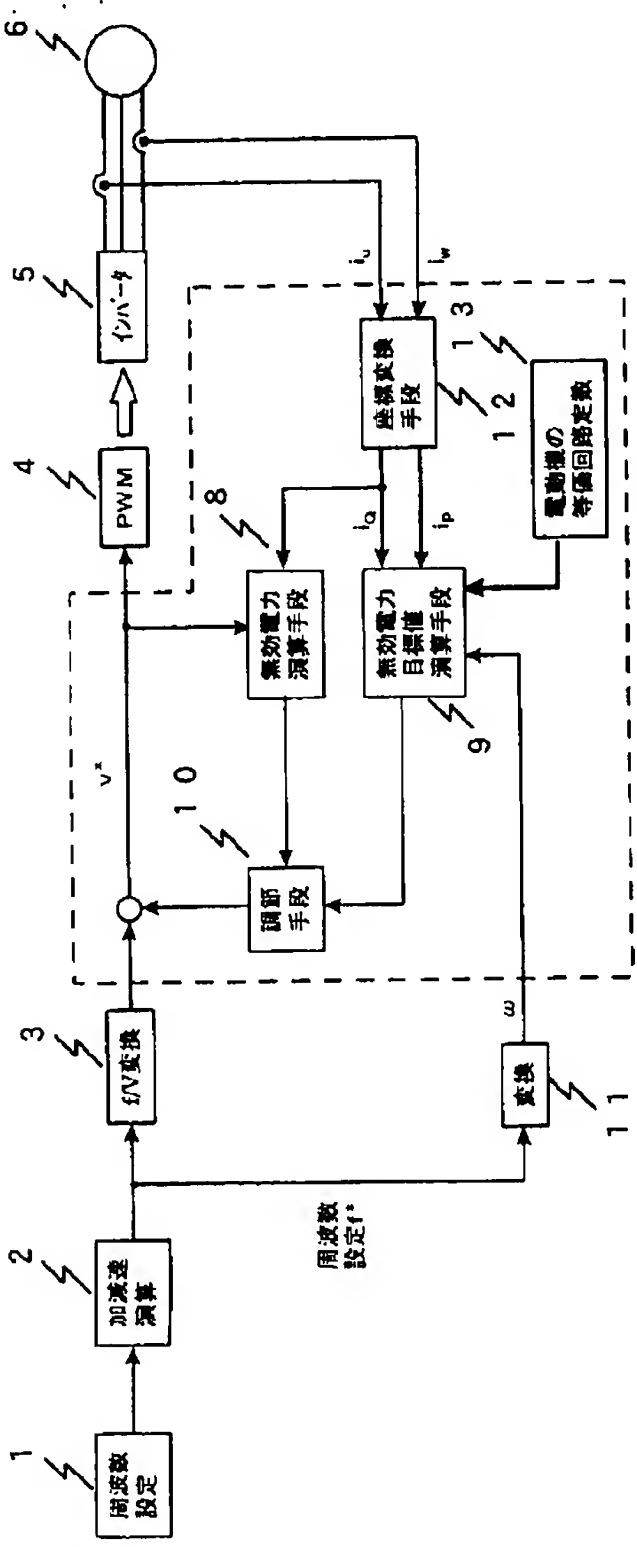
---  $\left[ \frac{K_p}{sT} \right] \rightarrow$  例④

$K_p$ : ゲイン定数  
T: 時定数  
s: 複素数

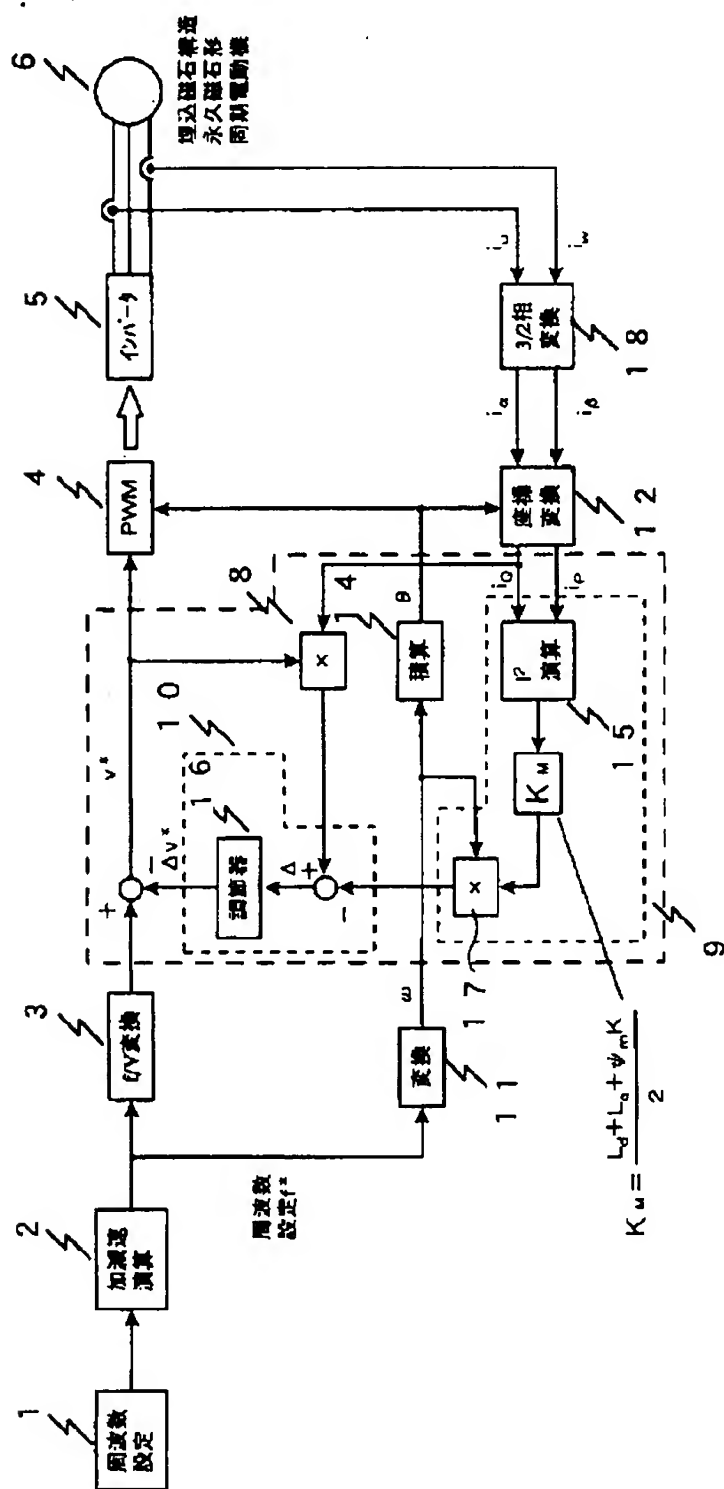
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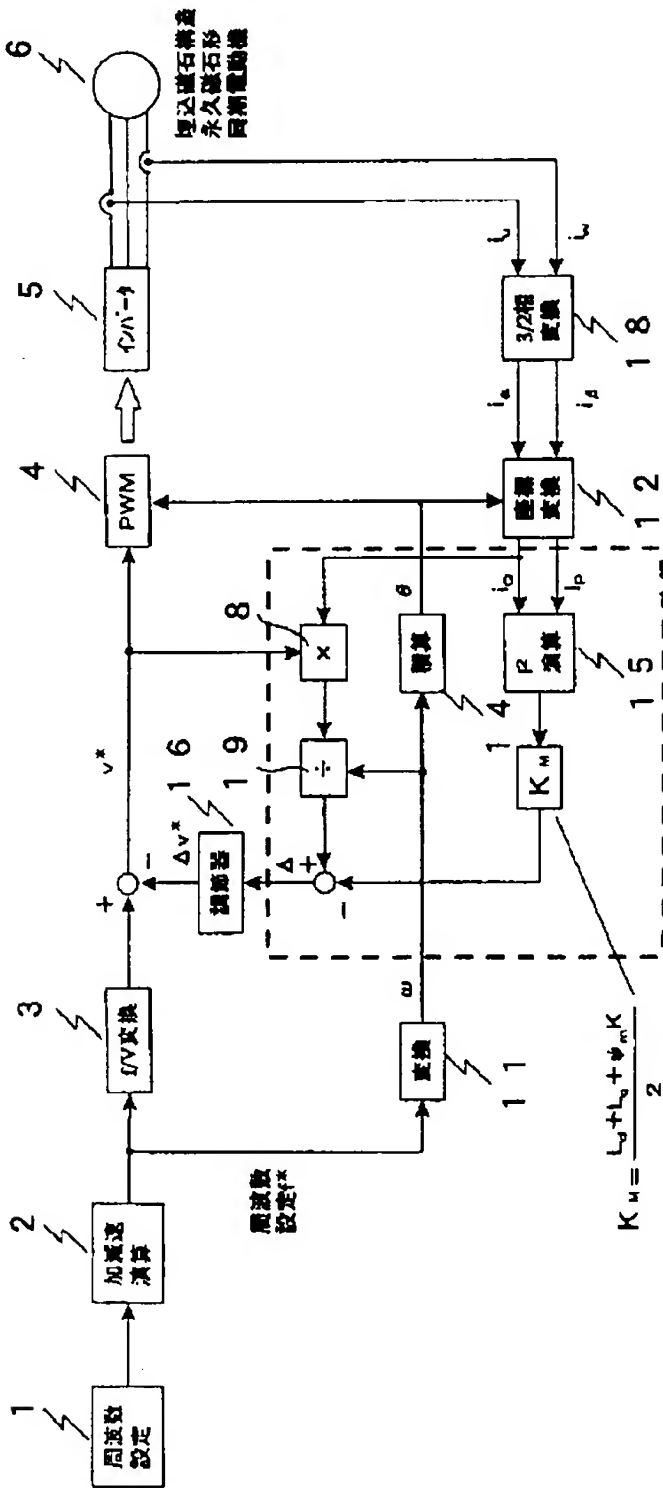
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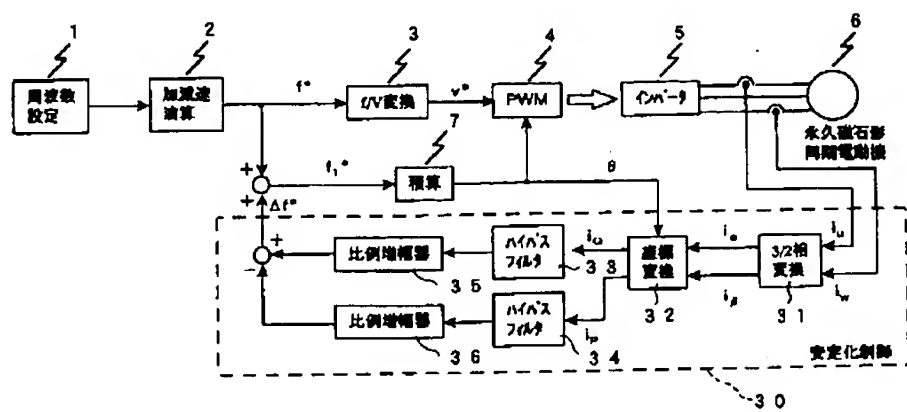
[Drawing 3]



[Drawing 4]



[Drawing 8]



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